Stream Simulation Design Process

Assessment
Stream simulation feasibility
↓
Project alignment and profile
↓
Verify reference reach
↓
Bed shape
and material
↓
Structure width,
elevation, details
↓
Mobility / stability
↓
Design profile control →

- Profile range
- Sustainability
- Floodplain function, connectivity
- Safety factor

Final Design and Contract Preparation

Stream Simulation
How big is it?

Final Design Details

- Select a structure type, shape and size to meet design objectives
- Structural design, foundations

Section 11 – this afternoon

- *Stream simulation materials and placement methods*
- *Specify or guides for erosion and pollution control*
  - *Dewatering, sediment control*
  - *Erosion and pollution control*
- *Contract Details (handouts or in book)*

Culvert Size
1. Based on Project Objectives:

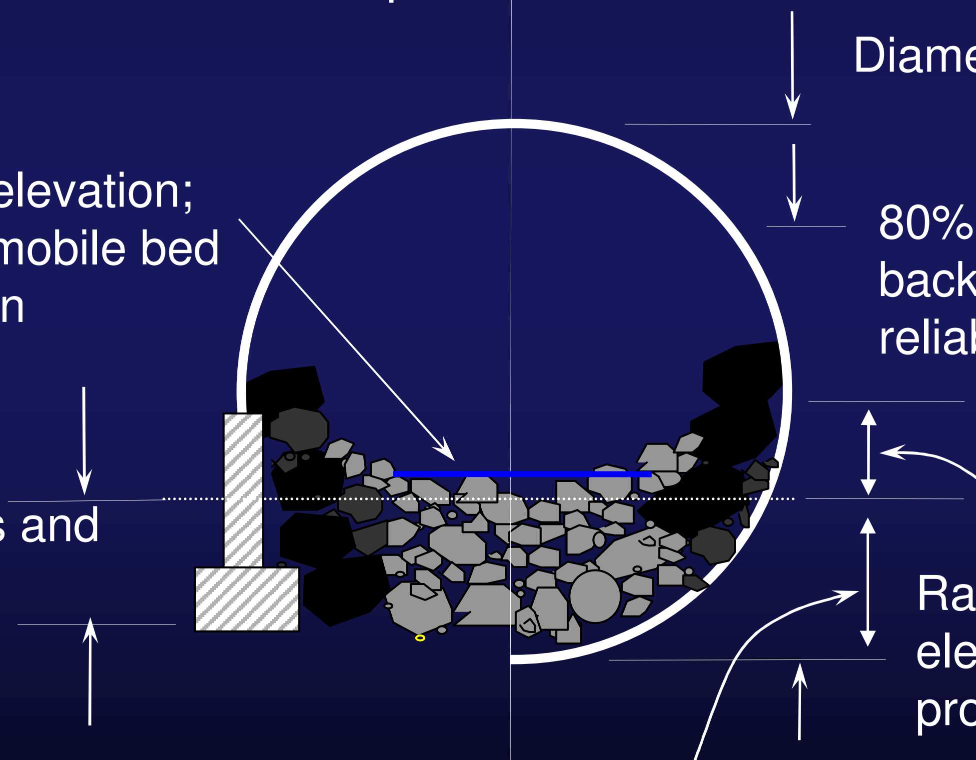
- Width of channel with banks
- Bed self-sustainability and stability
- Hydraulic capacity of the culvert
- Risk of blockage by floating debris or beaver activity
- Construction, repair, and maintenance needs
- Passage of non-aquatic species
- Meandering channel pattern part of project objectives
- Protection of floodplain habitats

Culvert Size
2. Based on Site Conditions:

- Channel migrating laterally
- Wider channel expected in future
- Channel skewed to road crossing (can skew some culverts)
- Ice plugging in severe cold climate
- Large bed material relative to culvert width
- High water level stage during floods or high tides.

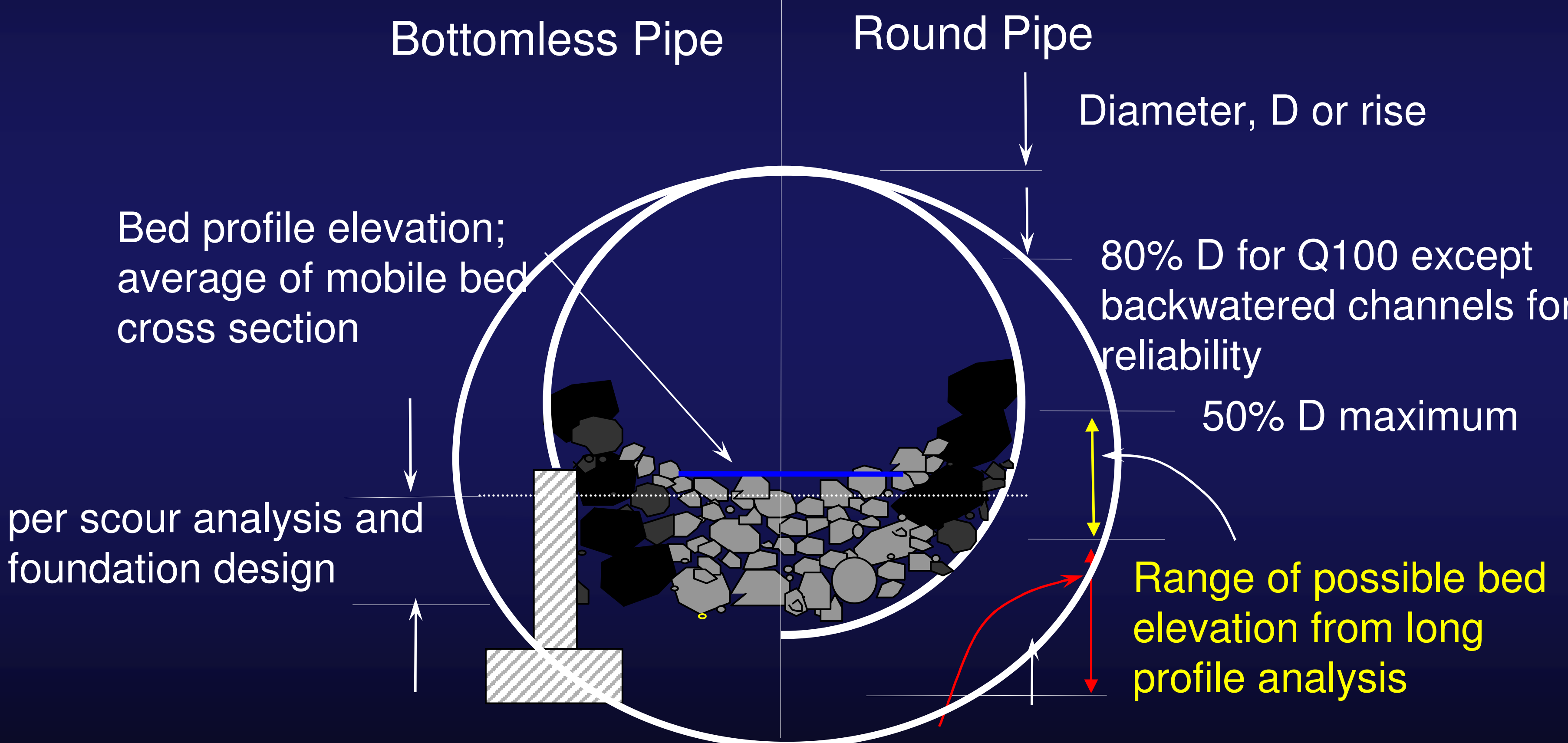
- Approximate crossing structure dimensions and invert elevation
- Flood-plain drainage structures

Culvert Elevation



~ Pool depth plus 2.0 x D_{95} local scour, average less in culvert but don't make too thin or it can nick and unravel bed material. One reason to build bed really well using compaction (vibratory compaction recommended).

Sometimes a closed bottom culvert is not a feasible based on scour unless bigger for deeper embedment



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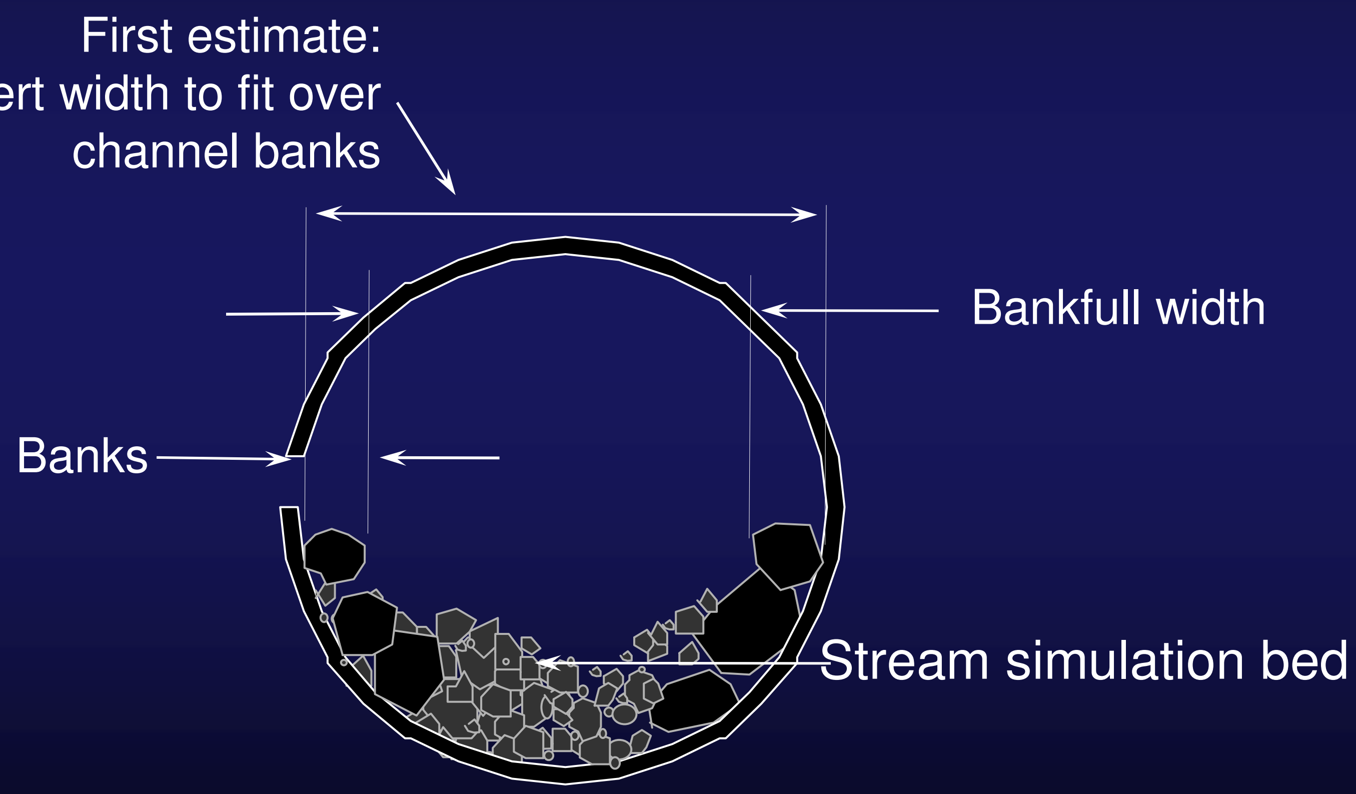
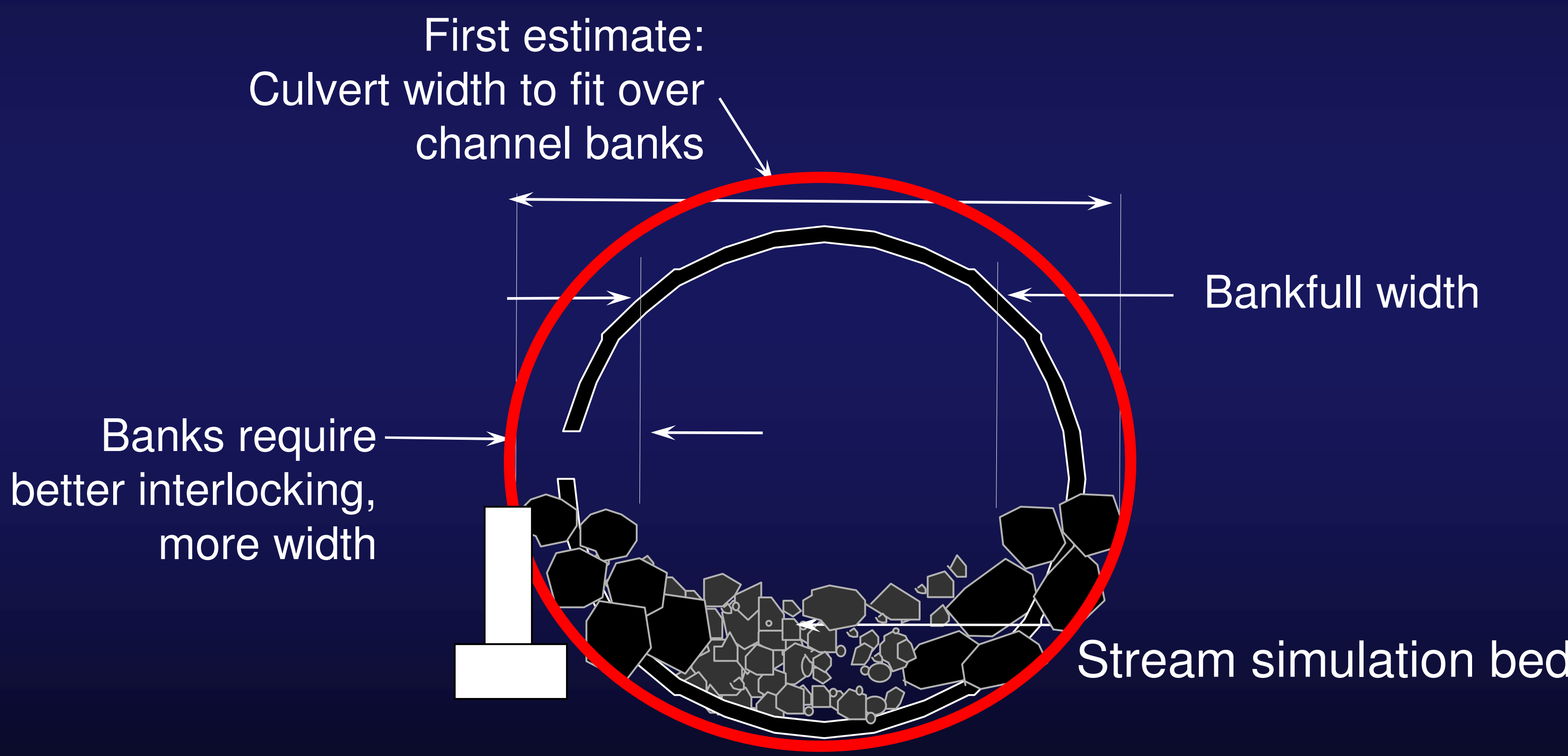
Stream Simulation - gentle gradient
First estimate of culvert width



Stream Simulation - gentle gradient
First estimate of culvert width



Stream Simulation culvert width

- Structure sized to fit over channel and banks
  - First estimate
  - Bankfull channel matches reference channel
    - Dynamic bed characteristics are simulated (self sustaining)
- Debris passage is optimized
- Consider contraction during higher than bankfull events
- Check hydraulic capacity varies region to region!
  - Stability: If Q50, Q100 pressurizes culvert bed may be scoured out or embankment fail.
- Openness ratio meet for terrestrial wildlife passage?

Wildlife Passage at Road Crossings

Openness Ratio

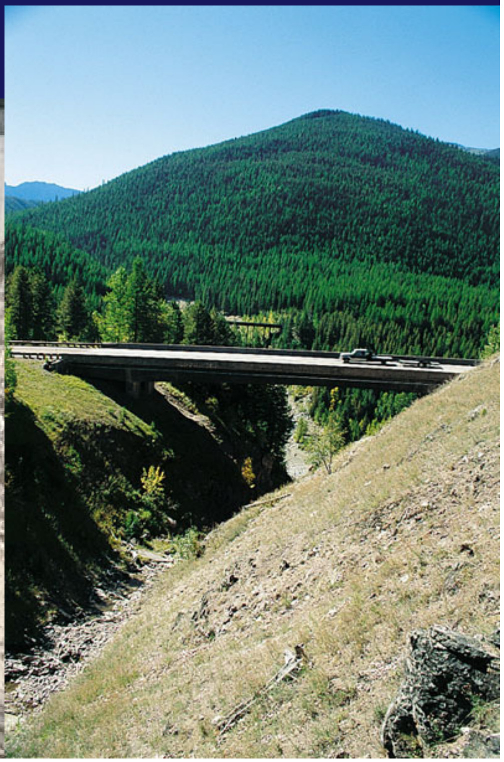
The characteristic of a passage structure related to the ability of an animal to see through the structure and not feel confined while within the structure. The Openness Ratio is calculated as

$$3.28*(\text{height X width}) / \text{length} > 1$$

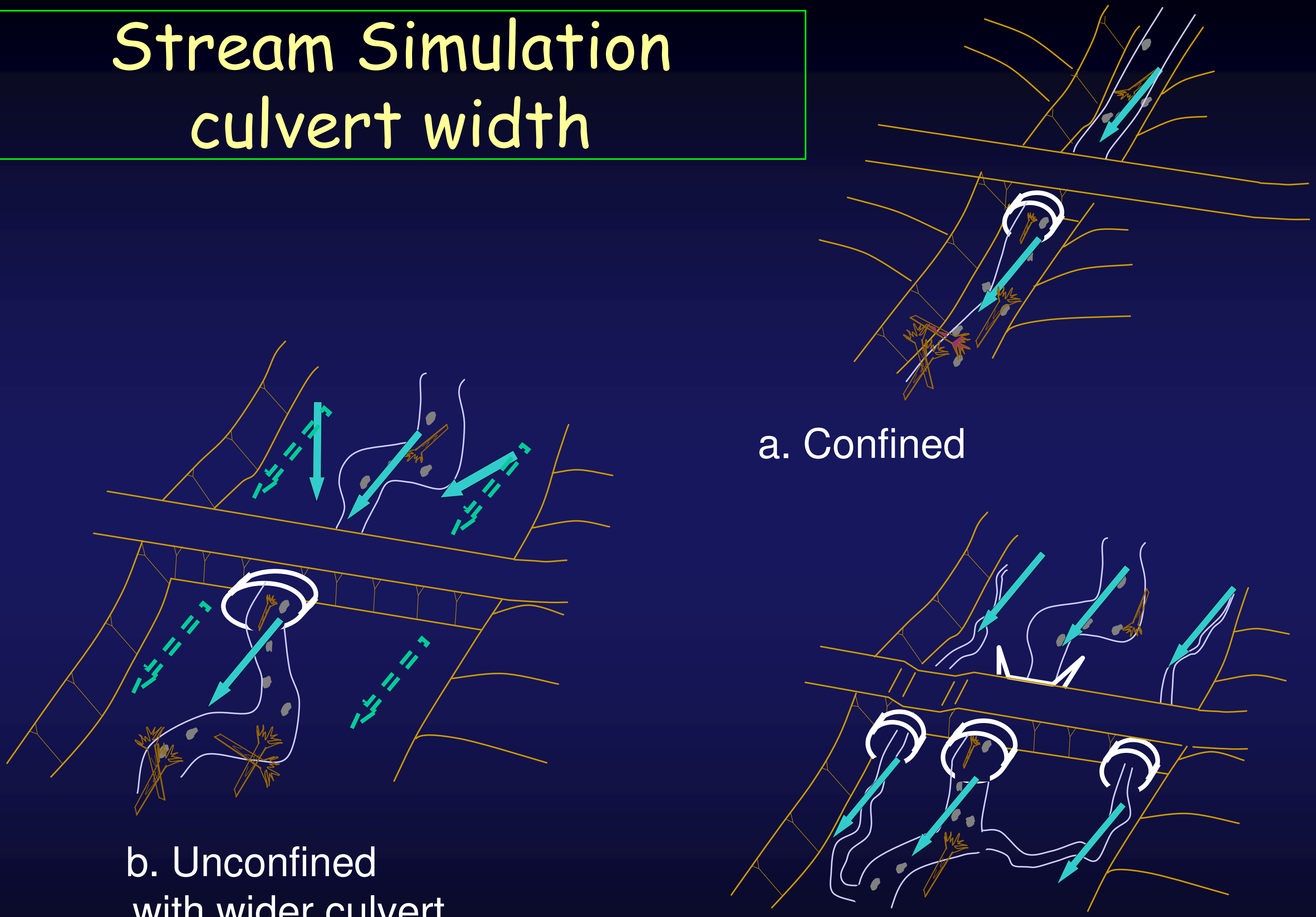
Goat underpass

Wolf underpass

Elk Overpass



Stream Simulation culvert width



a. Confined

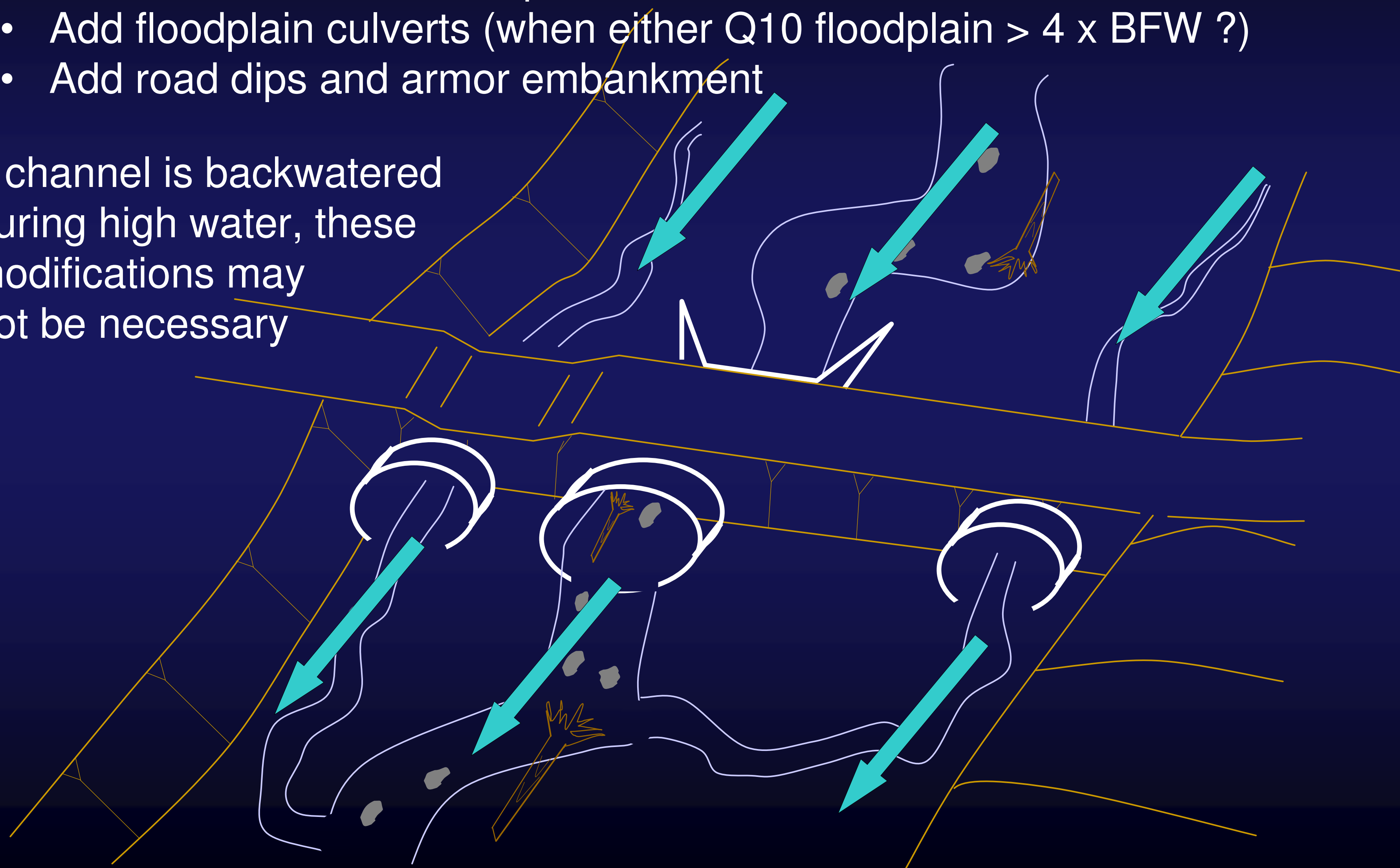
b. Unconfined
with wider culvert

c. Unconfined
with floodplain culverts

Unconfined channel - consider these modifications

- Hydraulic / Stability analysis when floodplain conveyance high
- Increase culvert width, Improve inlet contraction
- Add floodplain culverts (when either Q10 floodplain > 4 x BFW ?)
- Add road dips and armor embankment

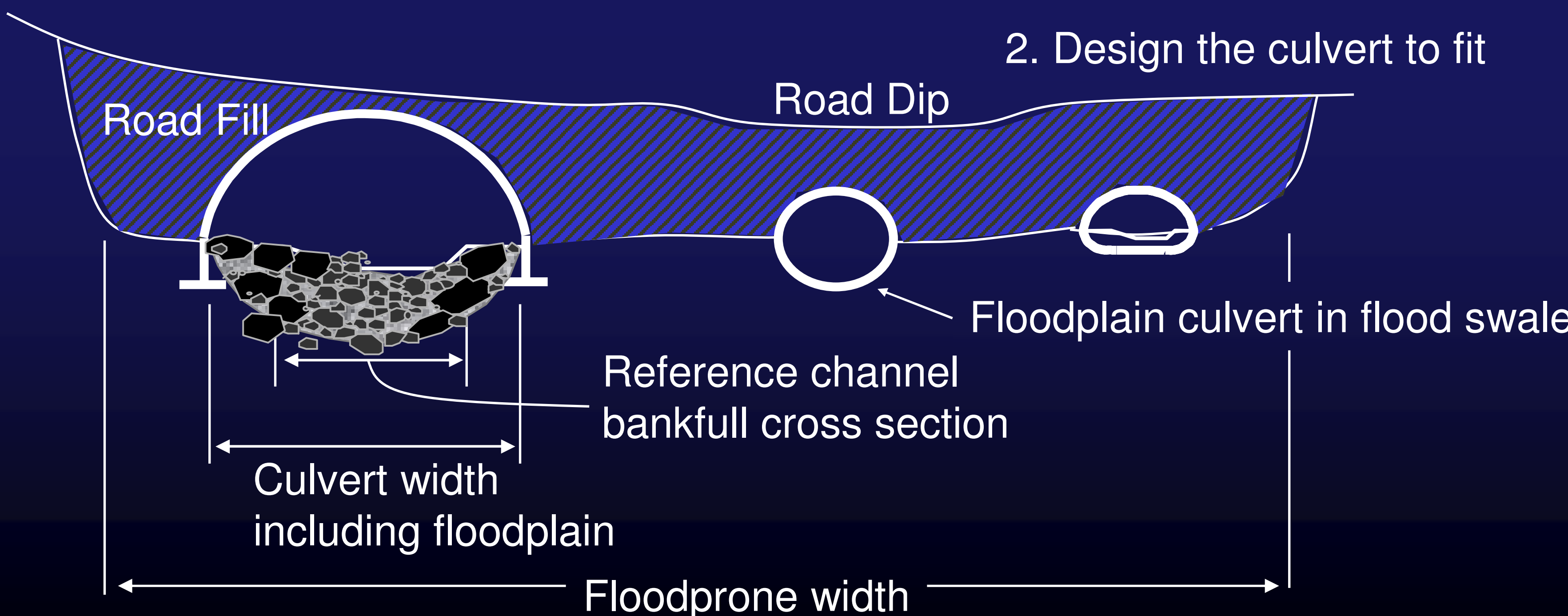
If channel is backwatered during high water, these modifications may not be necessary



Design for sustainability, especially when backwatering is limited or absent

1. Design the channel and floodplain

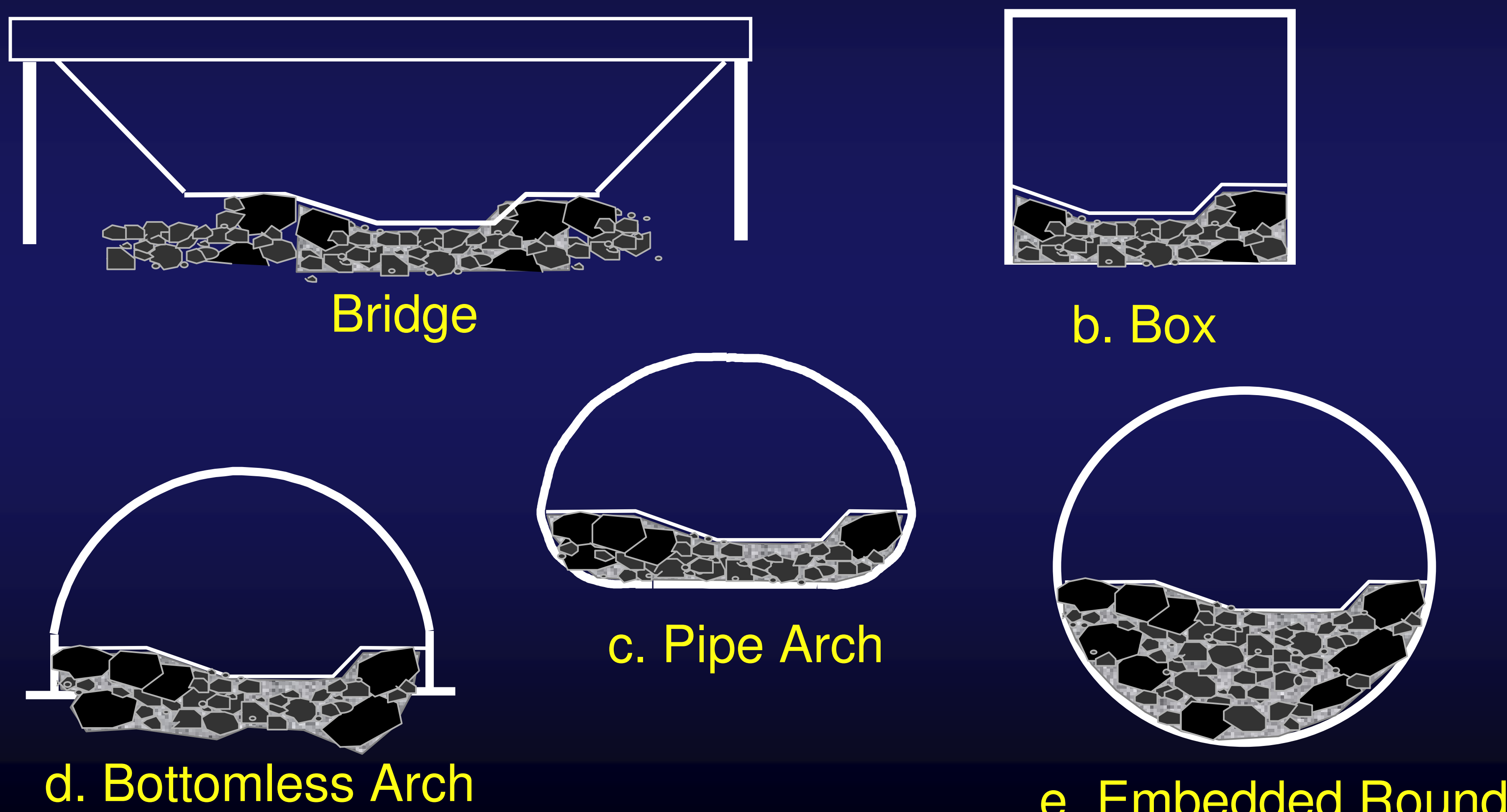
2. Design the culvert to fit



Structure Selection Considerations

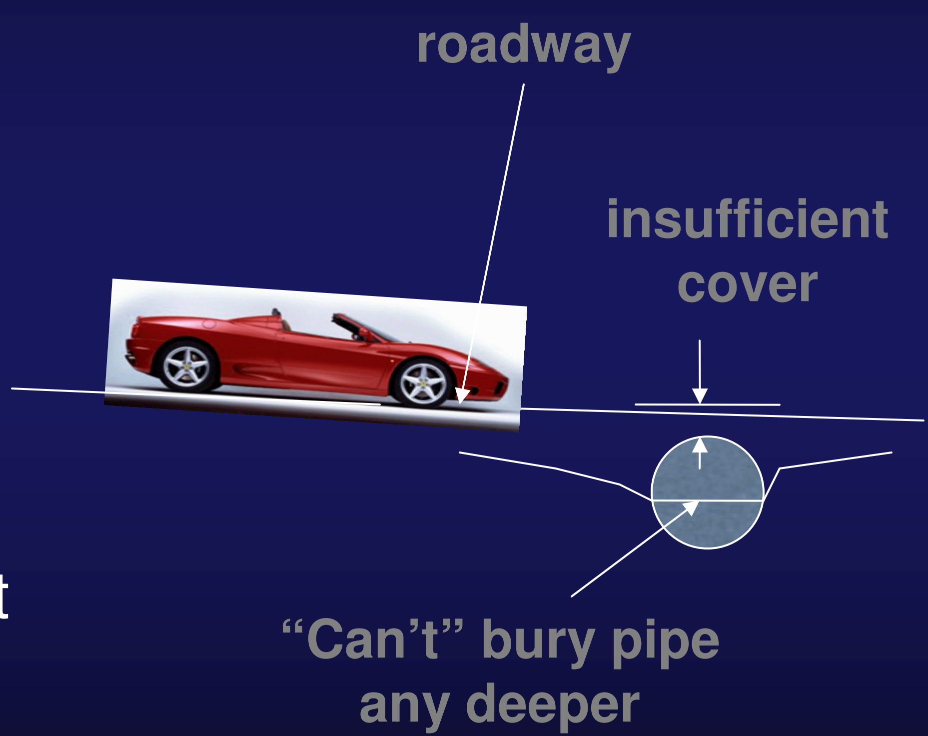
- Fit
- Cost
  - Durability
  - Risk
- Construction complexity considerations
  - Traffic, ROW, Contractors
- Short-term impacts

The same stream simulation can usually be constructed in any type of structure given enough embankment height;
Adequate embedment depth and constructability can be limitations.



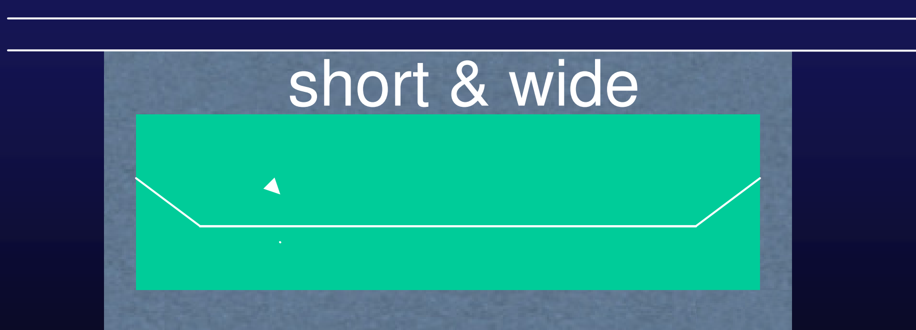
Structure Type and Cover Height

- Structure shapes are available to fit almost any site condition
- Some can be embedded deeper than others
- A low embankment height limits your options

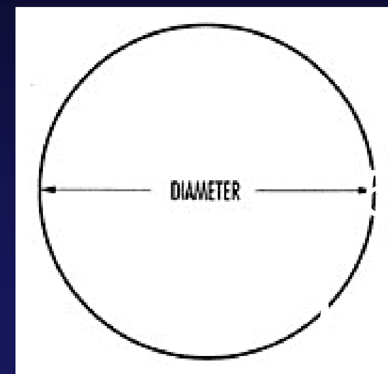


Pipes

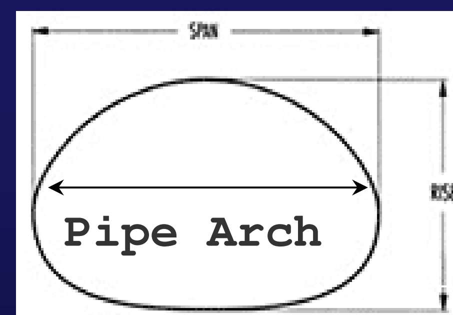
- Maximum embedment = where pipe is widest
- Sometimes need more embedment depth than a pipe can provide
- Up to 37’ wide (horizontal ellipse)



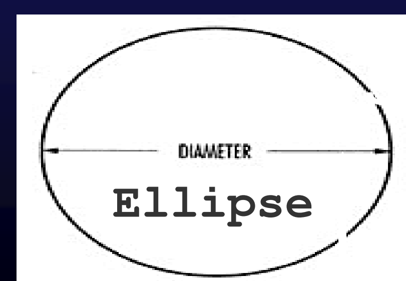
Embedment depth varies, designer has a choice



0%*span



20-35%



0%*span

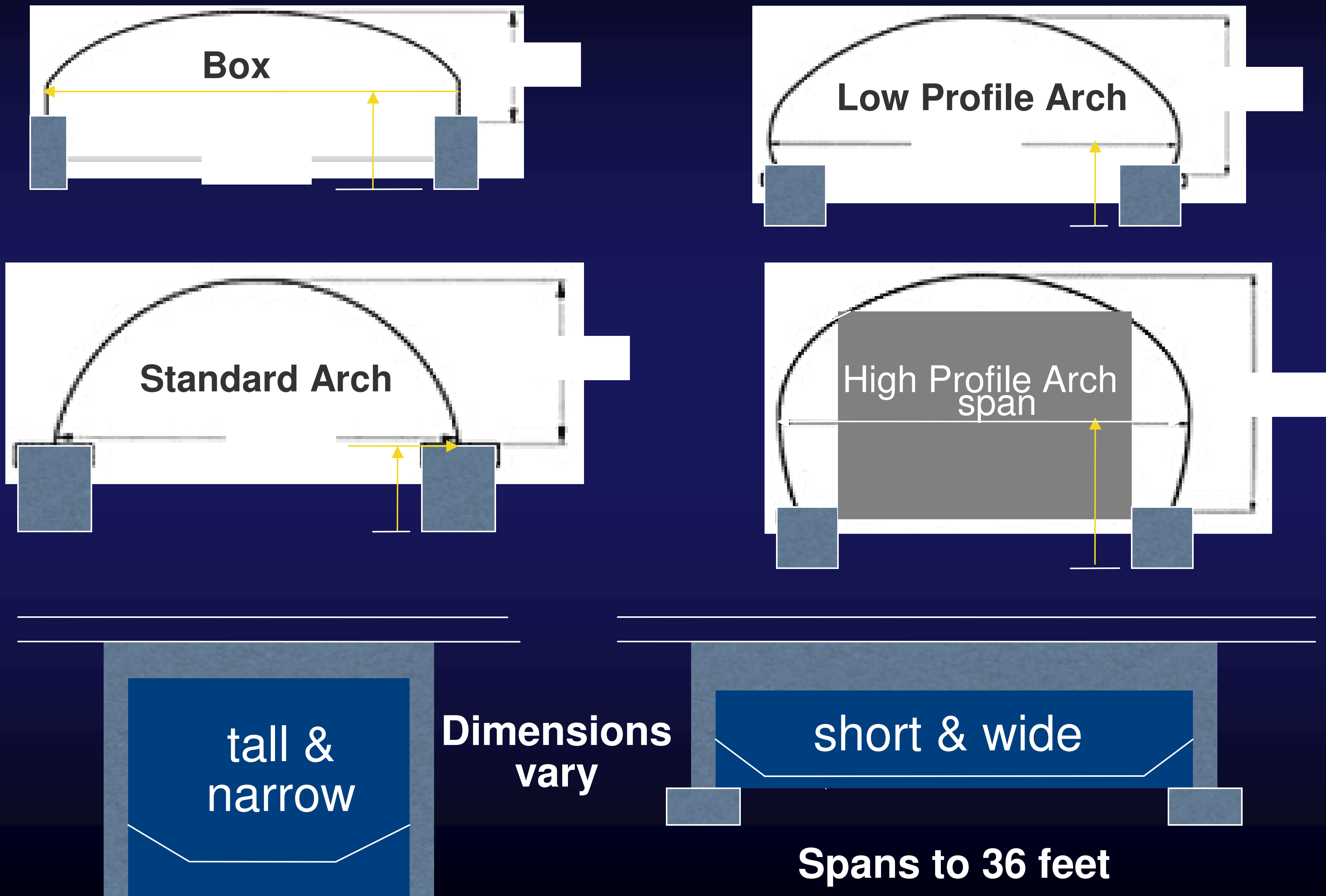

Pringle Ck.
Stream width 9.1 ft, slope 5%
Culvert bed width 9.3 ft, slope 6%
Unit Power = 6.3 ft-lb/sec/ft³
Barnard


Barnard


Hooper Ck .
Stream width 8.7 ft, slope 4.8%
Culvert bed width 11.4 ft, slope 5%
Unit Power = ?
Barnard

Arches

(embedment depth = footing depth +/- design bed elevation)



Structure Types--Examples

Standard one-piece pipe spans to 12 feet or 15 feet

Pipe arch multi-plate, spans to 21 feet, 37 feet w/ horizontal ellipse

Concrete arch/bridge", spans to 36 feet, more for other shapes

Box culvert multi-plate with metal footings, spans up to 40 feet

Bankfull width structure after 16 years

Width ratio: 1.0, slope 4.5%

Johansen

Bridges

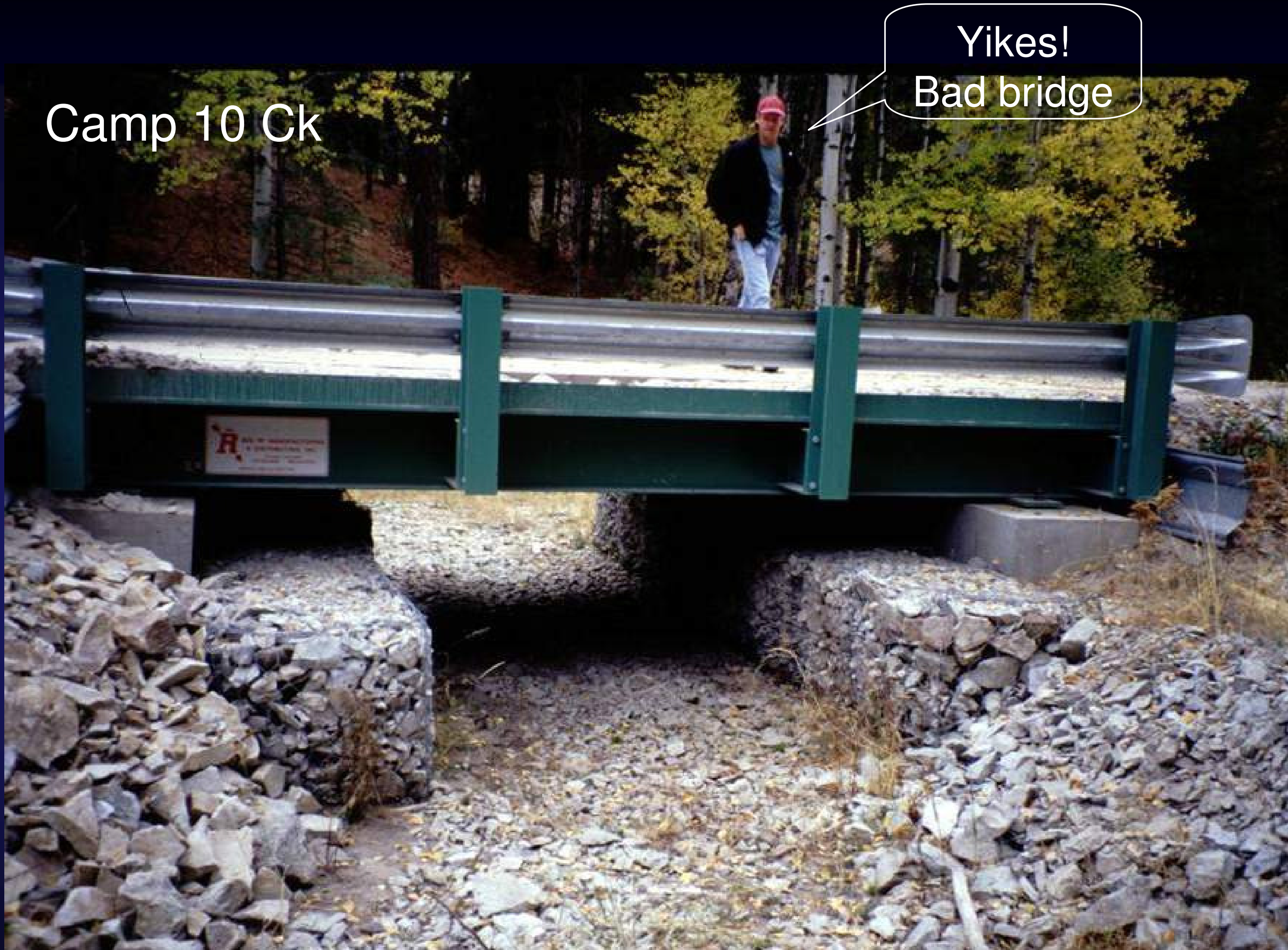
- Foundation can sit on soil or rock foundations and usually consist of:
  - driven piles: good for soft soils, any soil, or when driven to bedrock - noisy
  - piers – usually drilled to bedrock or to firm ground
  - retaining walls – shorten bridge but may cost more overall
  - spread footings – economical where channel is stable.

Bridge Structures

Pre-stressed concrete, pile foundation on bedrock is durable, economical

Wood: Glue laminated, trusses, sawn timber, logs, treated & untreated, economical

Steel: Permanent or temporary, some modular, painted or weathered steel for durability



Not necessarily better just because it’s a bridge.

Bridges are beautiful, but don't forget about stream channel restoration

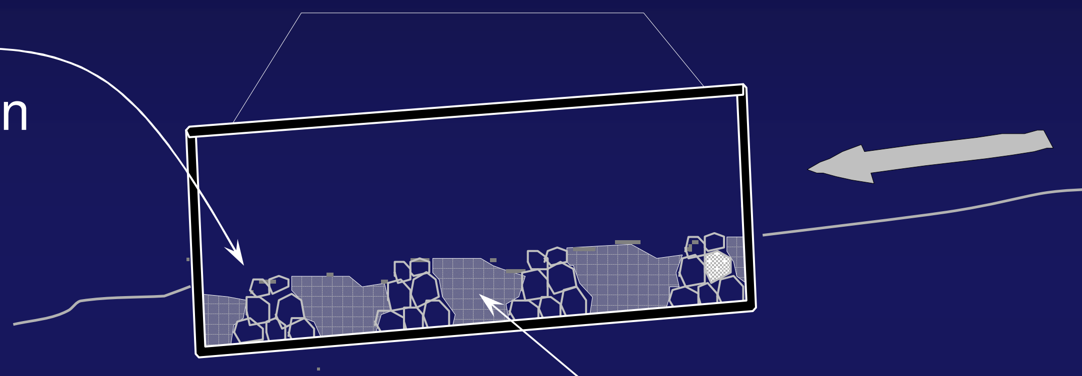
Photos have been modified to protect the guilty.

One year later, after head cut occurred, foundations are @ risk, riprap is undermined and unstable, footing has settled and rotated ~ failed.

Greater than bankfull

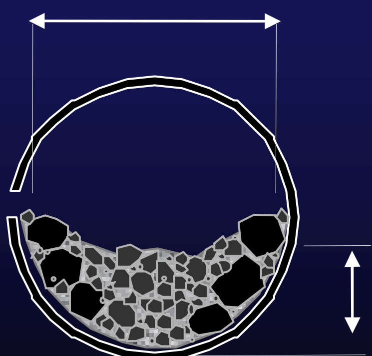
Complete Stream Simulation Design

Steps or rock bands
• Bands to control shape in low gradient
• Key features and banks



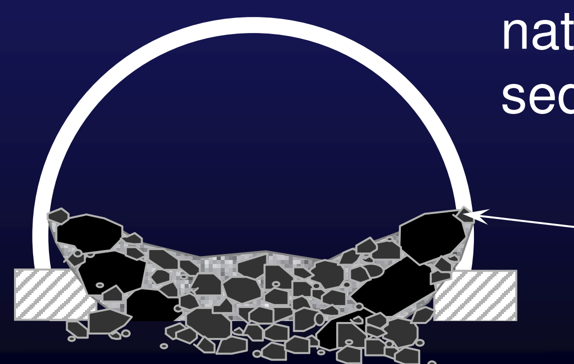
Well-graded homogeneous native streambed sediment mix

Culvert sized to fit bed and banks



Range of profiles,
No submergence.

Minimum $2xD_{100}$



Bankline

Geometry & Fit Considerations

- Road grade can be raised to improve structure fit.
- A roadway dip can reduce flood damage if the pipe is plugged but reduces the available cover height and may cause a jump in cost.
- Very large embedded pipes may need to be buried very deeply to fit within the roadway. This needs to be considered in dewatering. A change in culvert shape can reduce embedment depth (Round vs.. Pipe Arch)

Geometry & Fit Considerations

Hydraulic Check for ~ Q100, not just bankfull flow

- Bankfull flow is around 25% of Q100, 50% of Q50.
- Numerous larger flows will occur during the life of your structure.
- Bank full width may not be enough. Mimic the channel.
- A pressurized pipe will scour the stream simulation bed
- The receding flood may or may not replace that material
- Assure you have enough opening area and height for debris.
- For long term durability, design the stream simulation bed and culvert size to be as stable as the channel or increase stability
- Critical elements are stream simulation gradation, key piece sizes, step sizes, compaction effort, vertical and horizontal alignment, embedment depth, etc. (all the site investigation data)

Structure shape versus channel shape
Embankment height above thalweg = BFW (12')

Example of fit solutions:

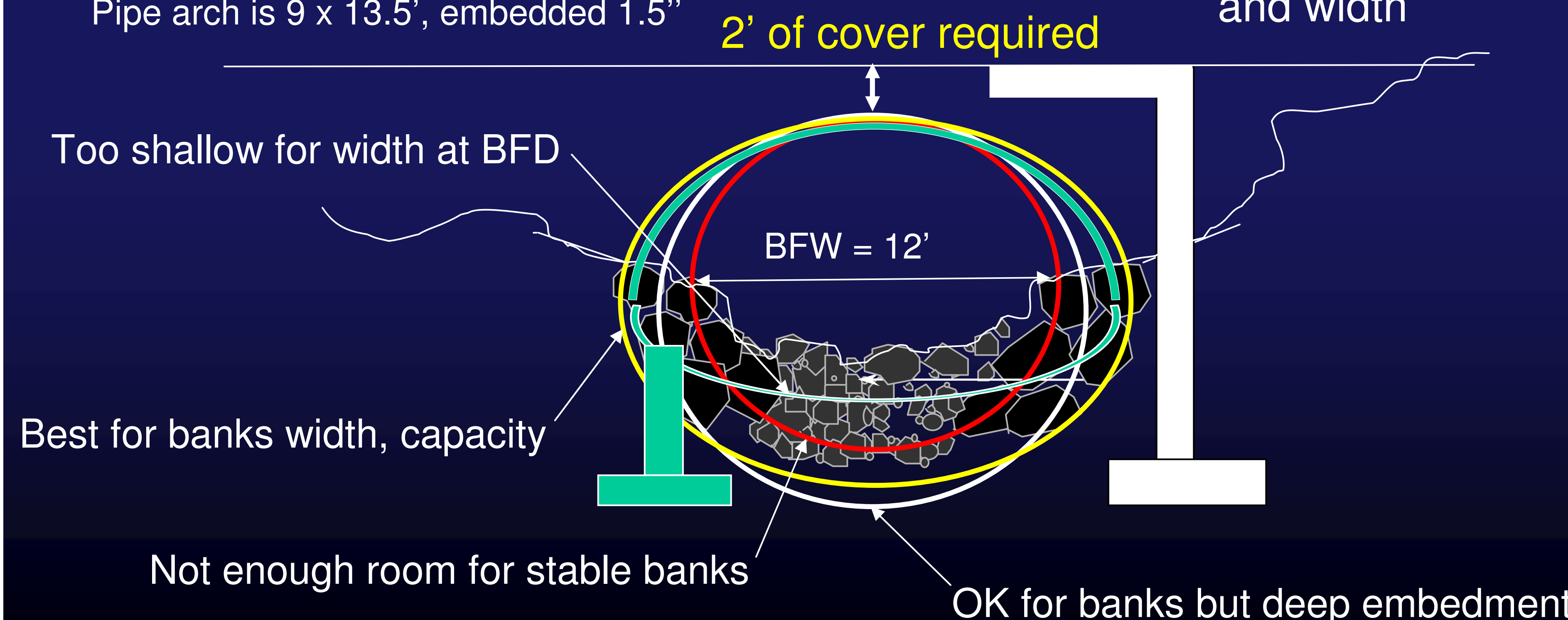
Smallest = 12' pipe, embedded 3.5'

Next is 14' pipe, embedded 6'

Ellipse is 11 x 16', embedded 4.7'

Pipe arch is 9 x 13.5', embedded 1.5''

Concrete box or bridge has flexible height and width



Structure shape versus channel shape
Embankment height above thalweg = 9'

Example of fit solutions:

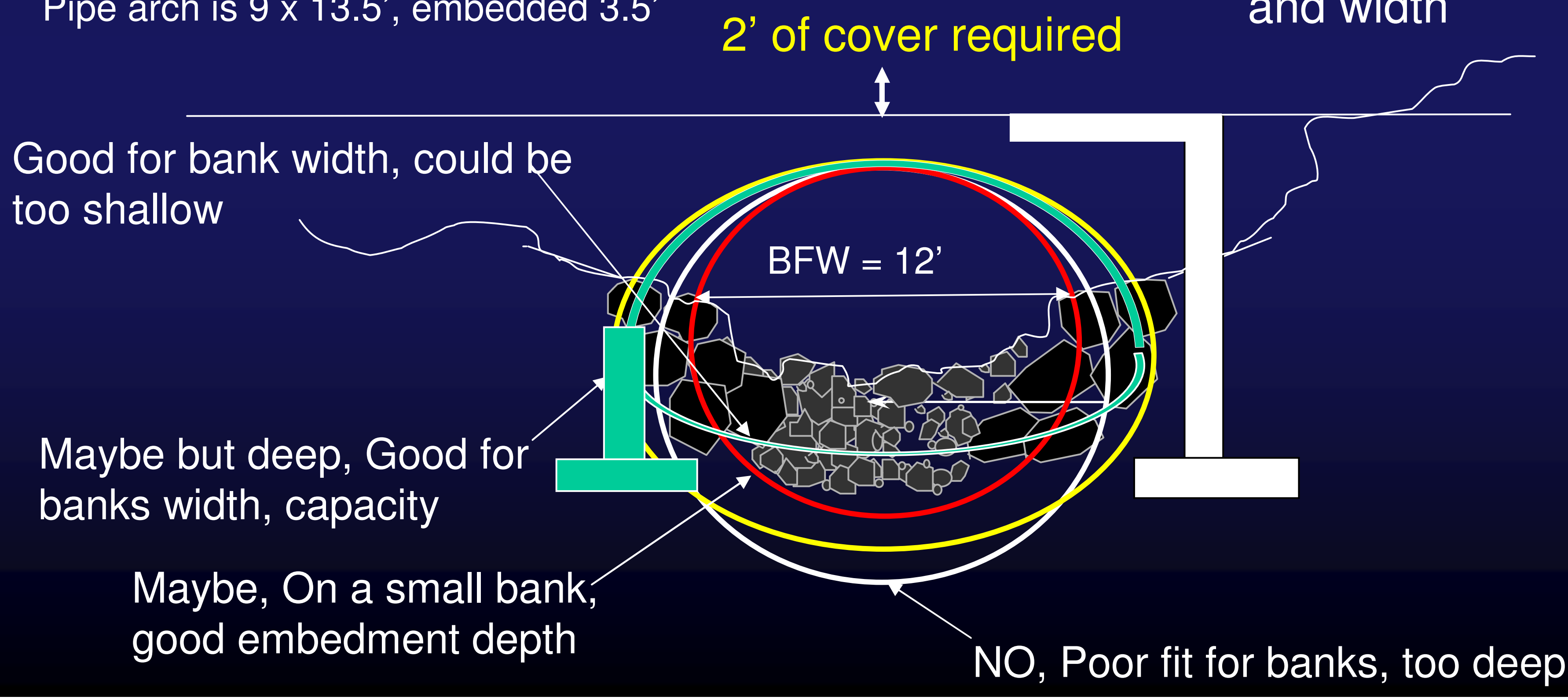
Smallest = 12' pipe, embedded 5.5'

Next is 14' pipe, embedded 7'

Ellipse is 11 x 16', embedded 6'

Pipe arch is 9 x 13.5', embedded 3.5'

Concrete box or bridge has flexible height and width

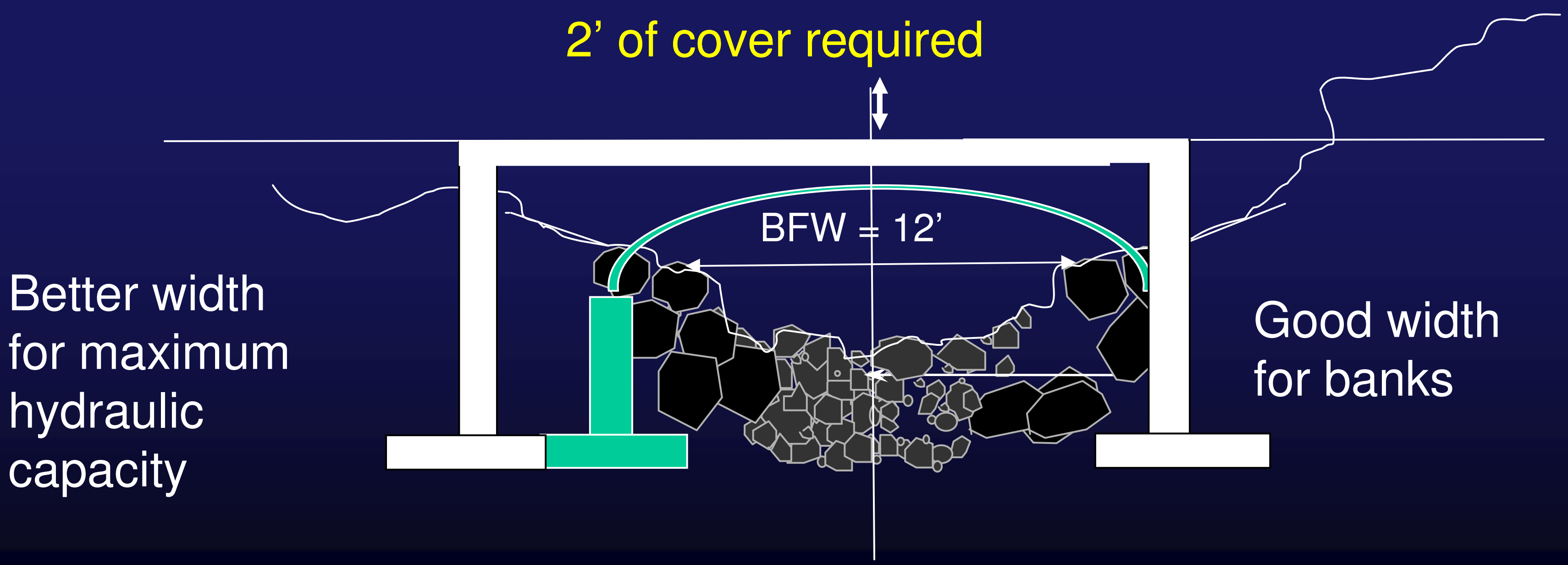


Structure shape versus channel shape
Embankment height above thalweg = 6'

Example of fit solutions:

Low Profile Arch, 16' wide, expensive due to shape and required thickness, Low hydraulic capacity.

Concrete box 16' wide or 24' valley spanning, or similar thin structural bridge deck gives the most hydraulic capacity and may be comparable in cost to low profile arch.



Example of structure type hydraulic differences,

4% gradient 12’ bank full width, 2’ bank full height, Q2=12-cfs, Q100=300cfs
(shifts are more dramatic at lower gradients)

STRUCTURE SHAPE	DIMENSIONS	Q2 INLET DEPTH	Q100 INLET DEPTH
Rectangular Concrete box	12’ wide x 6’ high	2.2’	4.1’
1/2 round arch or embedded pipe	12’ wide x 6’ high	2.6’	5.1’
Low profile arch	12’ wide x 4’-1/2” high	2.8’	6.7’

High and Low Profile Structures

Low fill = low profile structure = ($)

Embedded pipe arch

Aluminum box with aluminum footings

We don’t like multiple pipes to cross channel for a couple of reasons: velocity, scour at outlet, sediment trap, velocity, flood capacity

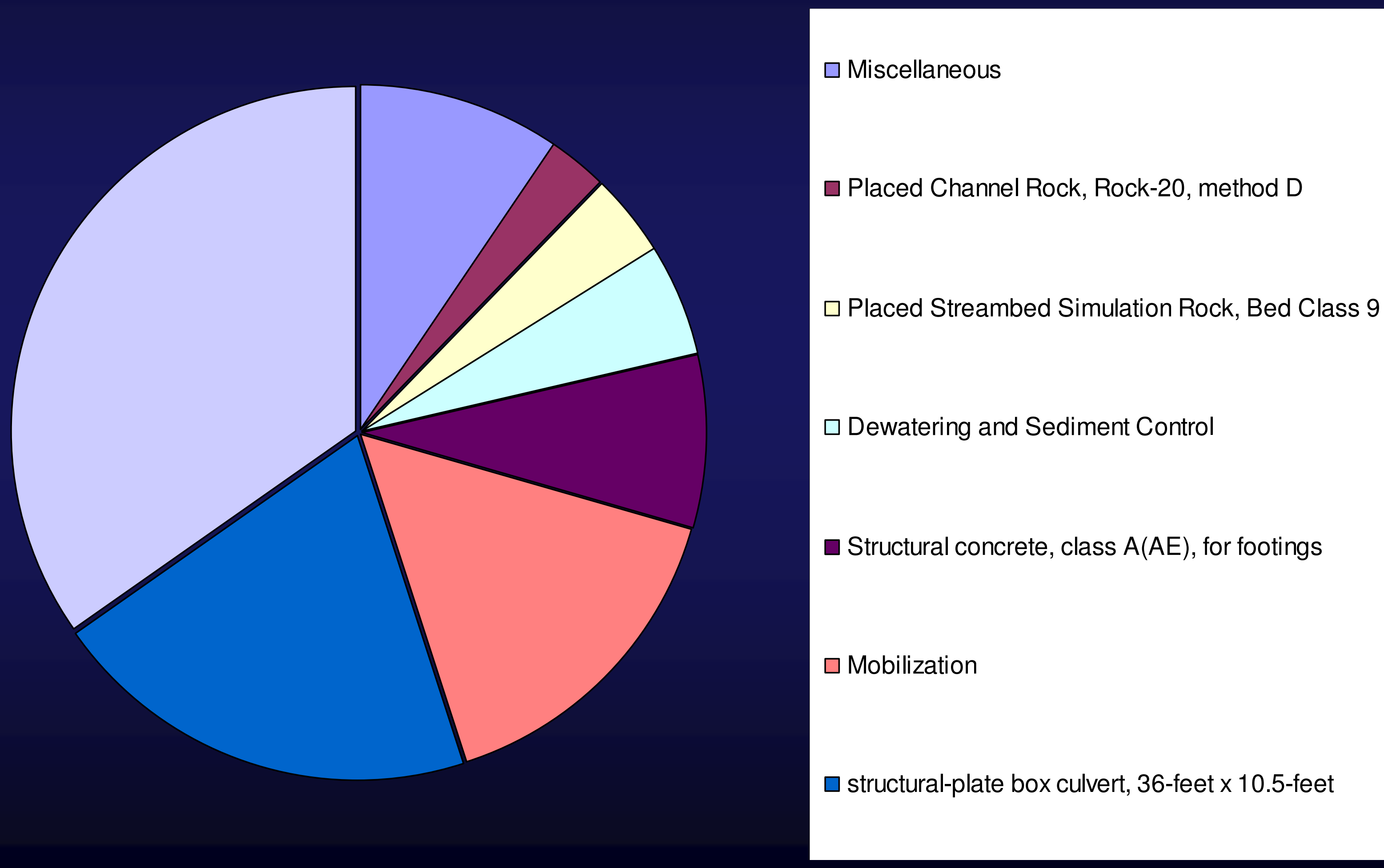
Relative Costs

Culverts and Arches can cost much less than bridges on sites with tight horizontally or vertically curved roads.

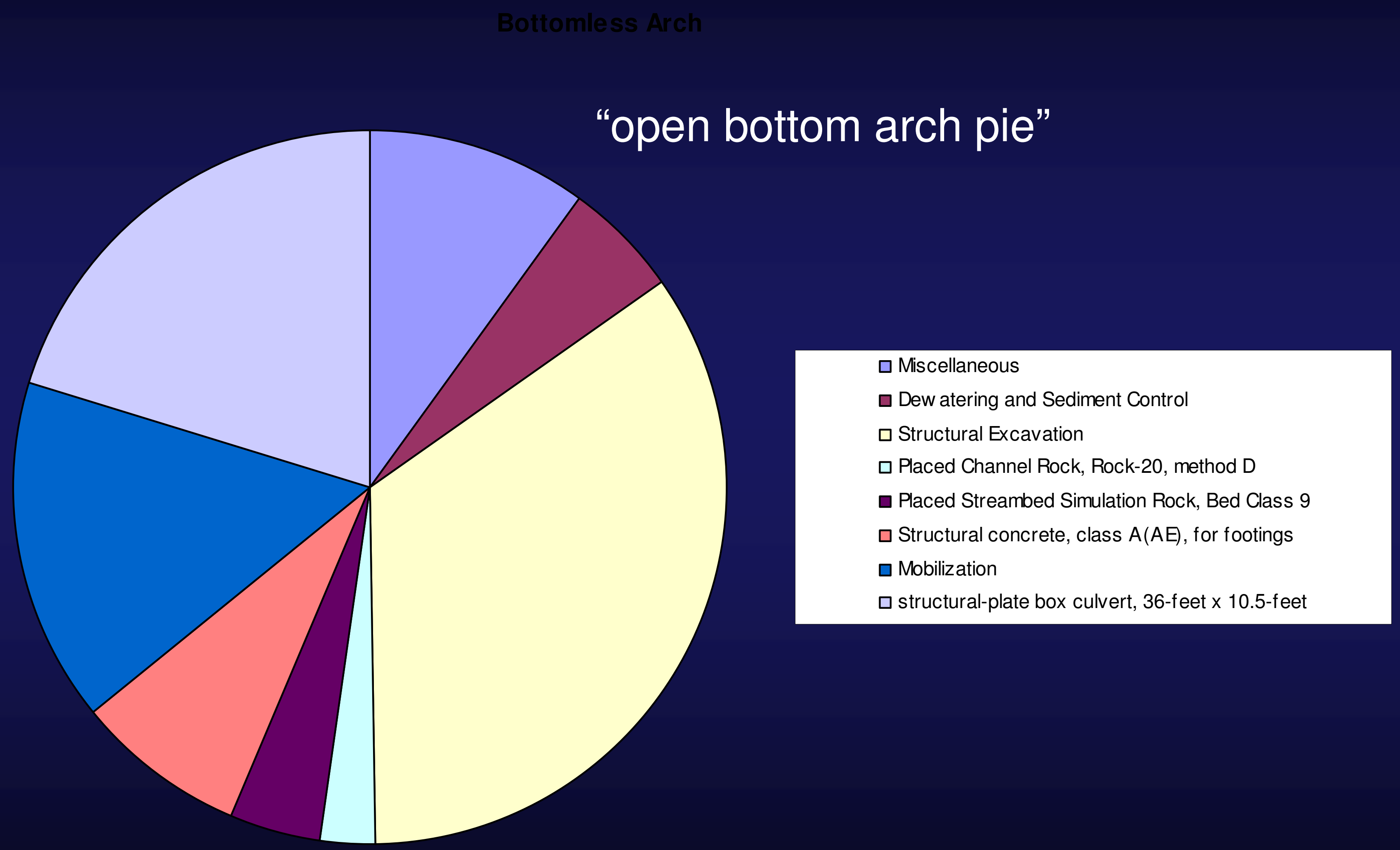
The need for a guardrail raises the cost of a culvert 5-15k, while they are frequently a normal part of bridge construction costs.

- width < 15 feet
  - bottomless arch
  - concrete box, bridge
- widths 15-30 feet
  - site conditions determine suitability and actual cost
- widths >30 feet
  - bridges

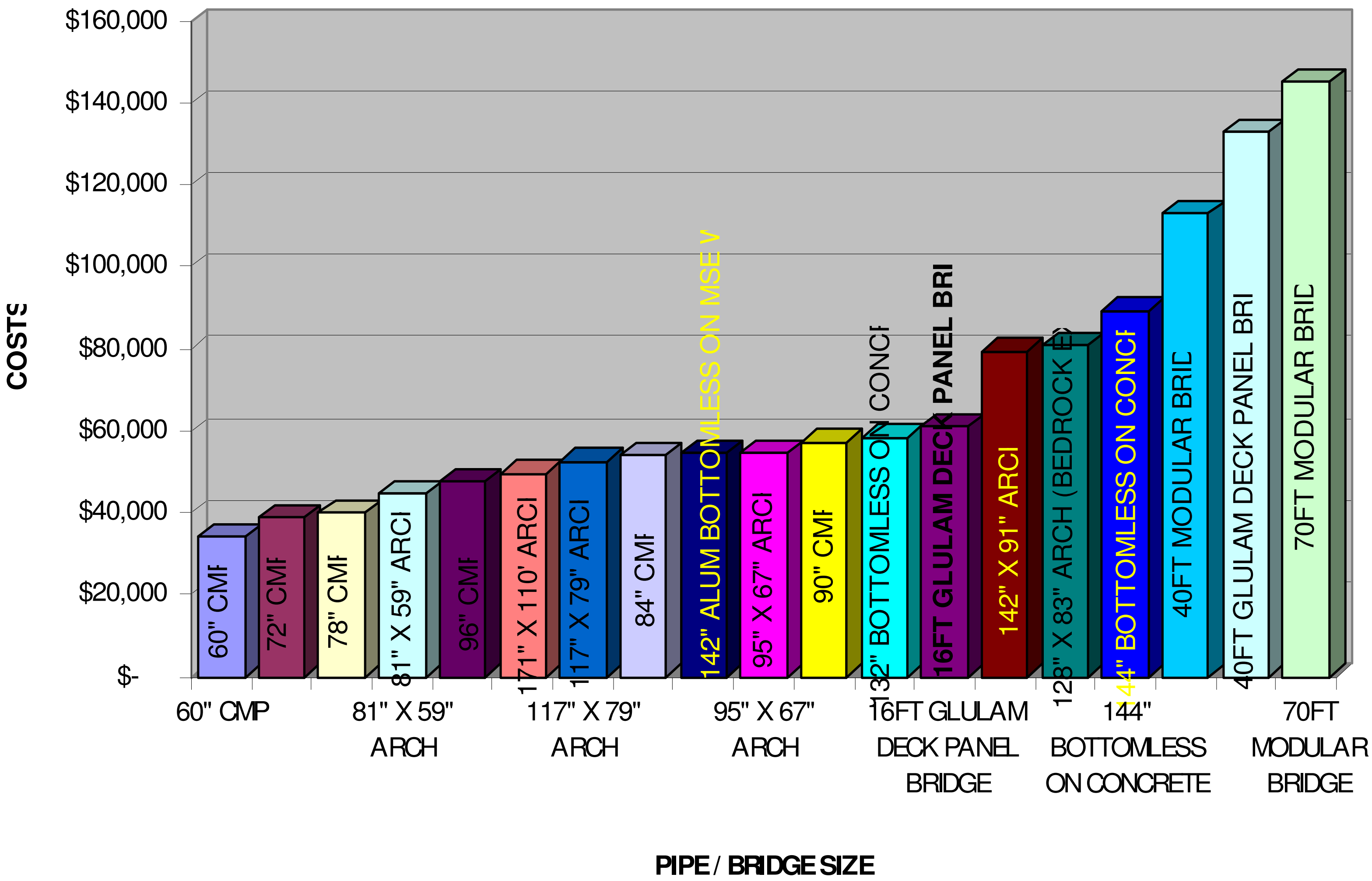
Bottomless Arch



Open Bottom Arch Costs



AVERAGE COST
TONGASS N.F.
2003



Changing from 12' open bottom arch to 18' OBA, 20' high road embankment, 80 feet long.

Foundation Fill	$4,000	+2,000
Structural Excavation	$24,240	+4,440
Constructed Steps (2 inside pipe)	$1,280	+480
Stream Simulation Rock	$8,775	+4,350
“Filler Material”	$400	+200
Aggregate Surfacing	$1,480	+80
Concrete Footings	$22,500	+5,000
Reinforcing Steel	$2,200	+43
Mobilization	$9,794	+3,728
Open Btm Multi-plate Pipe 12’, 18’	$33,060	+15,040
TOTAL CONTRACT	$107,729	+$35,361

50% width increase ~ 33% cost increase

Changing from 8′ open bottom arch to 12′ OBA, 20′ high road embankment, 80 ft long.

Foundation Fill	$2,650	+1,350
Structural Excavation	$22,960	+2,960
Constructed Steps (2 inside pipe)	$1,280	+480
Stream Simulation Rock	$5,070	+1,300
“Filler Material”	$400	+100
Aggregate Surfacing	$1,480	+80
Mobilization	$7,350	+2,060
One-piece Round GALV Embedded Pipe	$15,200	+7,000
TOTAL CONTRACT	$56,390	+15,330

50% width increase ~ 27% cost increase

Durability

- Abrasion –
  - from sediment transport: rate, size, shape of particles
  - removes culvert surface protection, reduced thickness
- Corrosion –
  - embedded pipe or pipe arch
  - rate increases after surface is abraded
  - rate: pH & resistivity
  - check for unusual corrosion rate at existing culvert
- Concrete Deterioration – can be a problem if mix quality is poor or If salts are used on the road, concrete deck will see shorter life spans

Durability - Abrasion

Abrasion rate depends on

- Sediment
  - size
  - density~ strength
  - shape (sharpness)
  - transport rate
- Flow characteristics

Material Abrasion Resistance

high

- **Concrete**
  - **quality important**
  - **resistant to abrasion**
- **Aluminum culverts**
  - **more vulnerable to sand**
- **Aluminized-steel culverts**
  - **more vulnerable to cobble**
- **Galvanized steel culverts**
  - **more vulnerable to cobble**

low

Durability - Corrosion Resistance

- pre-stressed concrete
- reinforced concrete bridges and culverts
- weathering steel or painted bridges
- aluminum culverts
- aluminized steel culverts (no multi-plates)
- galvanized steel culverts
- treated timber bridges (varies with treatment)
- untreated timber or log bridges

Most resistant

Least resistant

"Normal" Corrosion & Abrasion in a Galvanized Steel Culvert

Abnormal Corrosion
Galvanized Steel
backfill/groundwater properties

Oregon Department of Transportation Hydraulics Volume 1.

Table 6.1 PIPE MATERIAL SERVICE LIFE

Culverts, Storm Sewers, Under Drains
Average Years to Maintenance, Repair or Replacement
Due to Abrasion & Corrosion

Material	Location East or West of Cascades	Water & Soil pH	Soil Resistivity (ohm-cm)	Service Life
Galvanized Steel	East	4.5 – 6.0	1500-2000	30
	East	>6 – 7	1500-2000	35
	East	>7 – 10	1500-2000	40
Galvanized Steel	West	4.5 – 6.0	1500-2000	15
	West	>6 – 7	1500-2000	20
	West	>7 – 10	1500-2000	25
Aluminum	East or West	4.5 - 10	>1500	75
Aluminized Steel	East	5 – 9	>1500	65
	West	5 - 9	>1500	50
Concrete	All Locations	4.5 – 10	>1500	75+
Polyethylene	All Locations	4.5 – 10	>1500	75

1. For 16 gage galvanized steel, the service life increases for soil resistivity as follows:

Resistivity	Factor
2000 - < 3000	1.2
3000 - < 4000	1.4
4000 - < 5000	1.6
5000 - < 7000	1.8
> 7000	2.0

Soil Resistivity measures changes in conductivity by passing electrical current through ground soils.

2. Multiply the service life by the appropriate factor for different thickness.

Gage	14	12	10	8
Factor	1.3	1.7	2.2	2.9

3. Soil resistivity or pH readings outside the indicated limits will require special design considerations.

Structural Design- Sources of Information

Design information sources:

- Tables from books and brochures
- The manufacture can design the structure for you.
- Standard Specifications For Construction of Roads and Bridges on Federal Highway Projects, FP-03, US Department of Transportation, Federal Highway Administration, …covers structural design
    - Failure mode of buckling, handling, seam strength (usually weak link)

The minimum adequate structural thickness may be vulnerable to handling stresses, poor backfill methods, or unanticipated construction traffic loads (earth movers)

Know your traffic needs!

Bypass roads – adding later may require structure modification, $$$ So Plan Ahead, NEPA, fire access, recreation

- By pass roads are most suitable for Forest roads or Country roads where land is available for temporary construction & public traffic use.
- Highway designs often require 24/7 traffic.
- No bypass road but maintaining traffic usually requires construction of a long structure and the use of retaining wall to separate construction elevation from traffic elevation.

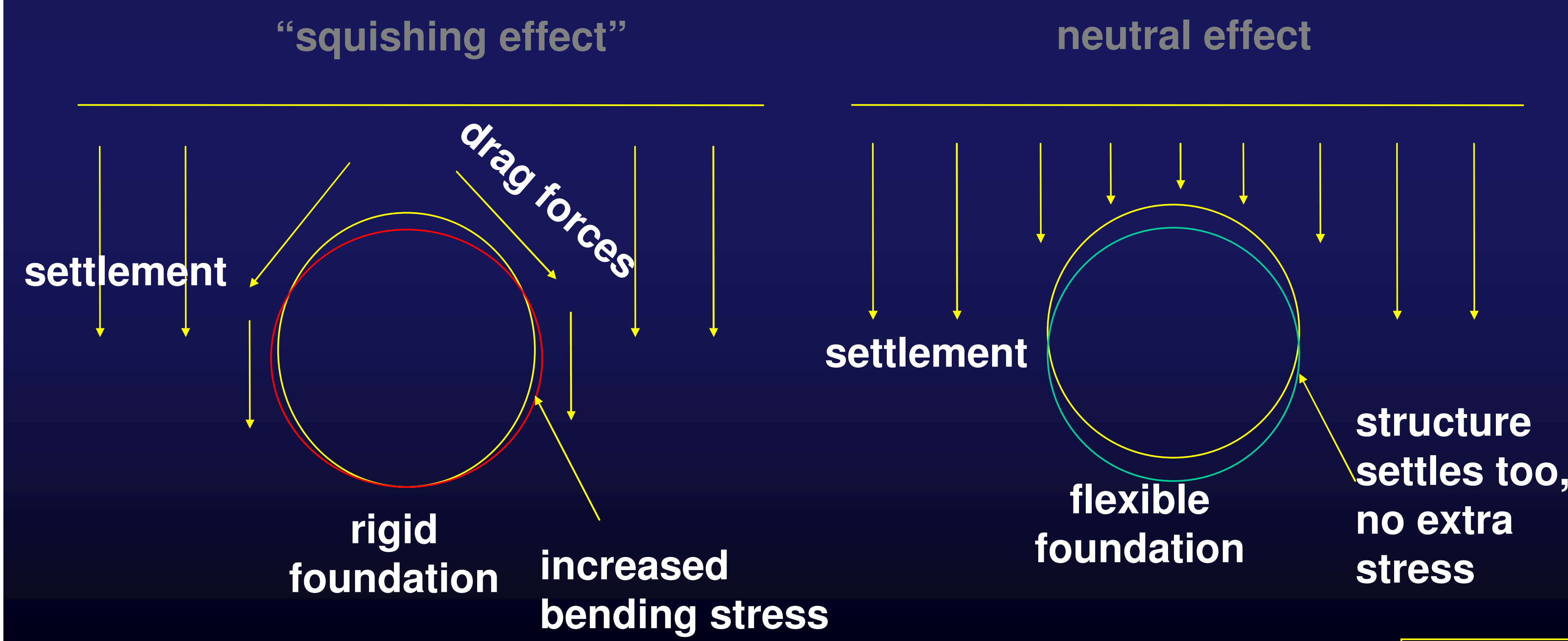
Foundation Conditions and Slope Stability Considerations

- Strength estimates for soil and rock units for design of foundations.
  - Rock to rock contact vs.
    - Sand (gradation dependant)
    - Can be problematic – Need a specialist to design footings and embedded pipe when settlement would cause problems (asphalt roads)
- Slopes - Design excavation slopes when AASHTO is too conservative. Do you use AASHTO Guidelines
- Dewatering is the key to getting good working conditions and a dryer foundation area.

Backfill, Settlement and Foundations

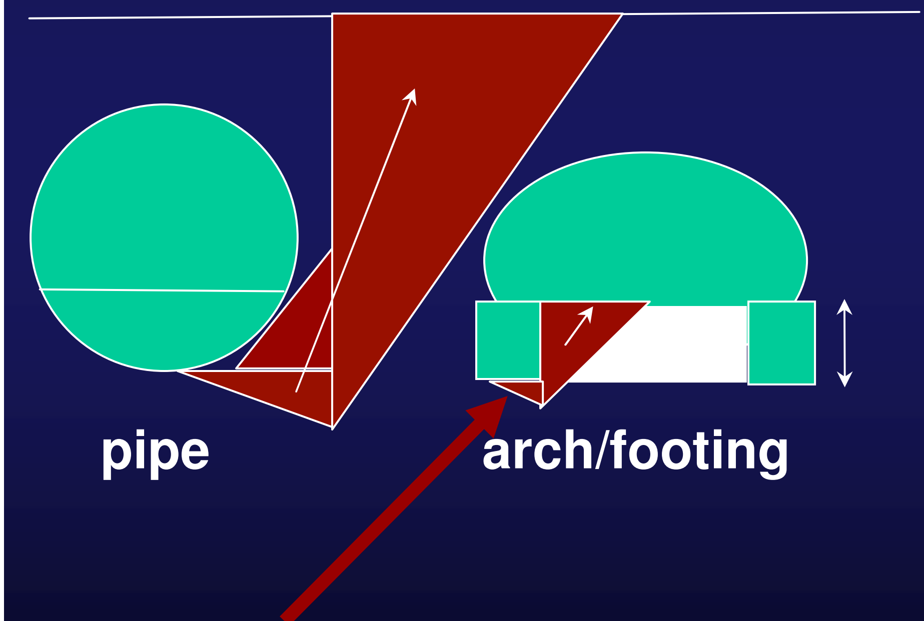
Controlled compaction is required, specify backfill and bedding according to the manufacturers recommendations.

Generally requires a low plasticity, granular material, easily compacted to prevent damage to culvert for excessive force and vibration effects.



AASHTO

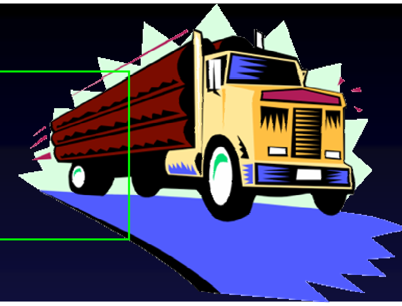
Bearing Capacity & failure modes

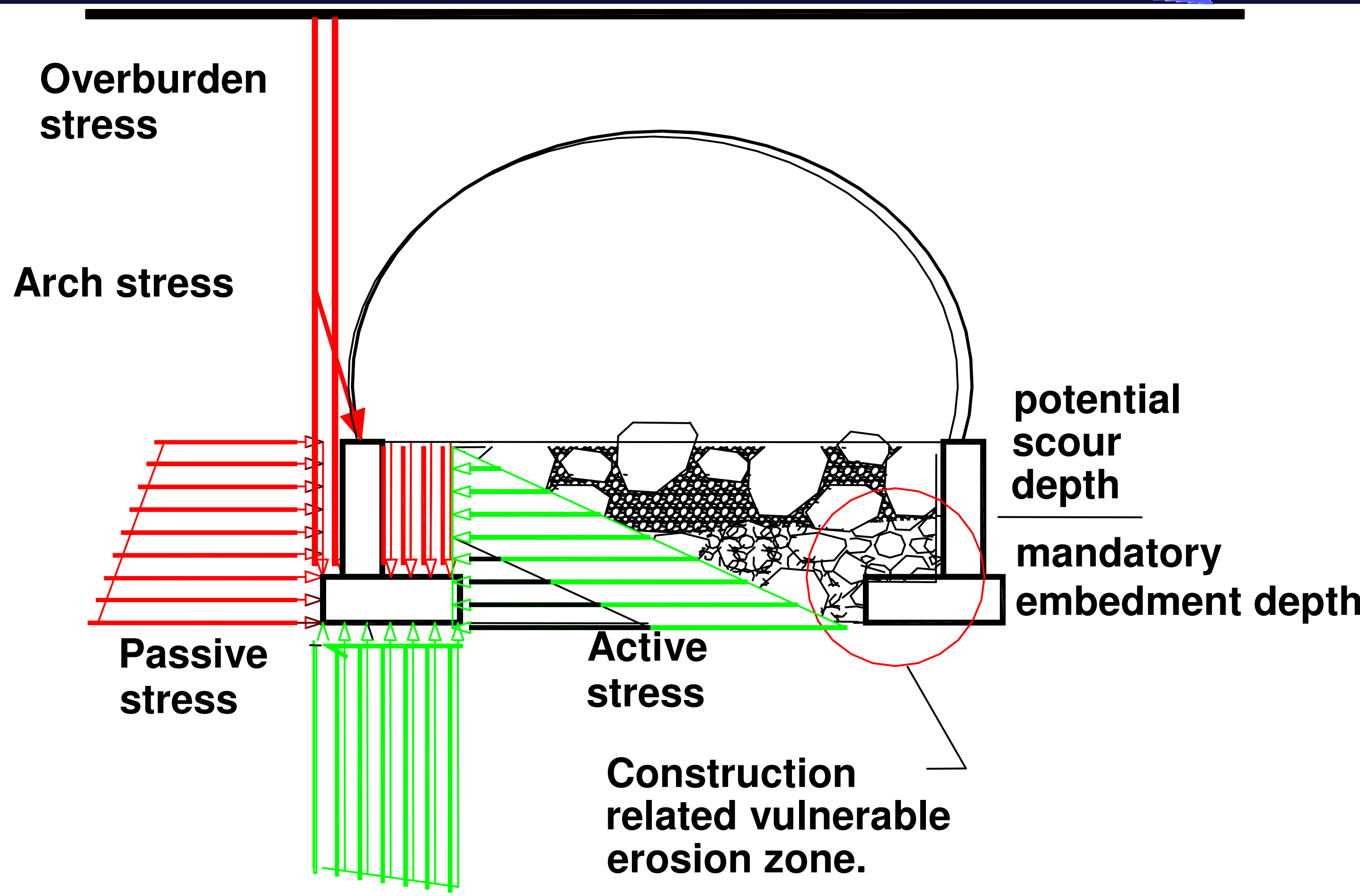


- Bearing Capacity of pipe is 2-4* open bottom arch.
- Pipes must fail through entire height of fill – seldom a concern. Settlement is a more likely phenomena.
- OBA footings designed to develop to reduce load to what soil can carry. depth & width are key.
- It is imperative to prevent scour below the footing design depth. – long profile

Zone of vulnerability, A minimum embedment depth is required to develop foundation bearing capacity in soil.

Foundation Design

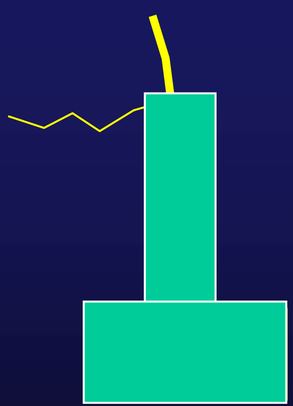




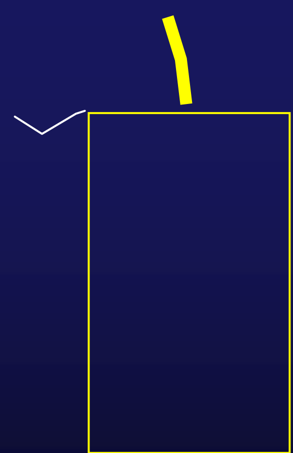
FOOTING STRESSES

Footing Shapes for Open Bottom Arches (OBA)

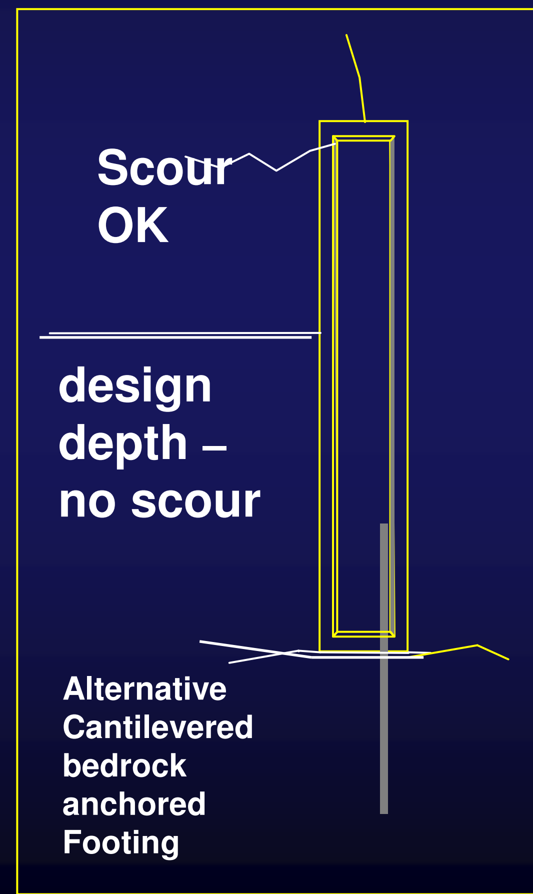
To remain stable, OBA footings require burial to a specific depth. Thus, scour below this depth may cause foundation failure.



Spread Footing



Alternative Rectangular or Wedge Footing



Exercise 7b

- Bed material design
  - (3a) Design bed mix for alluvial portion of bed
  - (3b) Key features, banks
  - (3c) Colluvium or other roughness
- (4a) Important characteristics for design

>>X10